SCIENCE

A WEEKLY JOURNAL DEVOTED TO THE ADVANCEMENT OF SCIENCE, PUBLISHING THE OFFICIAL NOTICES AND PROCEEDINGS OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

FRIDAY, OCTOBER 13, 1905.

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MSS. intended for publication and books, etc., intended for review should be sent to the Editor of SCIENCE, Garrison-on-Hudson, N. Y.

RECENT DEVELOPMENTS IN AGRICULTURAL SCIENCE.[1]

IN dealing with the science applied to a particular industry like agriculture it is convenient to draw a distinction between the class of investigations which seem to be contributions to knowledge pure and simple and those which aim at an immediate bearing upon practice. Both must be regarded as equally 'pure' science, since both should call for the same qualities of imagination and exact reasoning which characterize true scientific work; but while the one may appeal readily to the intelligent practical man, the value of the other can only be appreciated by the expert. The dividing line between these two branches of the subject is never a sharp one; indeed the most abstract and remote investigations are always cutting into the region of practise in a wholly unexpected fashion; but still the distinction I have indicated can be readily felt. To take an example—for the proper interpretation of many questions connected with the texture of soils and their behavior under cultivation—it is necessary to arrive at a clearer understanding than we now possess of the intimate causes which lead the finest particles of material like clay to unite together into floccules, or coagula, under the influence of traces of dissolved salts. Such investigations will touch upon some of the most debatable ground belonging to the theory of solutions and the constitution of matter, and can never be made intelligible to the

[1] Read at the South Africa meeting of the British Association for the Advancement of Science.

practical man himself; yet a knowledge of their results may be indispensable to the expert whom he consults about the character or management of his land, however trivial and workaday the actual question may seem.

In any agricultural experiment station worthy of its name, place should be found for investigations of this latter class; unfortunately many such institutions are under the necessity of showing 'results' which immediately appeal to the practical man and may be taken to justify the expenditure of public money; so that it is only by side issues, as it were, and by degrees, as the general public can be brought to trust its scientific men, that such work will be undertaken.

It is not my purpose, however, to deal to-day with this form of abstract research. I rather propose to point out certain lines of work in agricultural science which are now being pursued with increasing vigor, and which, from the very outset, promise to have considerable applications in practical life.

It is in the domain of agricultural bacteriology that perhaps the greatest progress has been recently made, in the main progress in connection with that perennial problem—the sources of the nitrogen of vegetation. From the very beginnings of agricultural chemistry, which we may very well date from the publication of De Saussure's 'Recherches Chimiques sur la Végétation' in 1804, discussion has raged round this point. Liebig, in his famous report to this association in 1842, regarded the atmosphere as the source of the nitrogen contained in the plant; but in the long controversy that followed, the view finally prevailed that the plant was only able to utilize already combined nitrogen in the soil, so conclusive seemed the experiments conducted by Boussingault and by Lawes, Gilbert, and Pugh at Rothamsted. But a fresh turn was given to the whole question by the discovery made by Hellriegel and Wilfarth in 1887 that the leguminous plants in virtue of the bacteria living symbiotically in the nodules on their roots were able to fix atmospheric nitrogen. From that time research has been directed towards the problem of utilizing and rendering more effective this particular *Bacterium radicicola.* Widely distributed as it is in the soil, it is yet not universally present; heaths and peaty soils, for example, that have never been under cultivation frequently lack it entirely; consequently, it is impossible to obtain a satisfactory growth of leguminous crops, upon which in many cases the possibility of successful reclamation is based, until this class of land has been inoculated with the appropriate organism.

Again, although but one species of bacterium seems to exist, yet several investigators have found that by its continued existence in symbiosis with particular host plants it has acquired a certain amount of racial adaptation, so that, for example, clover will flourish best and assimilate the most nitrogen if it be inoculated with the organism from a previous growth of clover, and not from a pea or a bean plant.

The conclusion naturally follows that it may be necessary to inoculate each leguminous crop with its appropriate organism in order to secure a maximum yield. The first practical efforts in this direction did not, however, meet with much success: the cultivations used for inoculation were weak, and, when sown with the seed, in many cases died before infection took place. Even when the formation of nodules followed, yet the assimilation of nitrogen was not great. The question in fact turns upon the degree of 'virulence' possessed by the subcultures used for inoculation. It is well known with other bacteria how their specific actions may be-

come entirely modified by growing on particular media, or at a high temperature, and even by long-continued growth under laboratory conditions.

B. radicicola does not develop very freely on the ordinary media used for the cultivation of bacteria, nor can it be made to fix much free nitrogen when removed from the host plant. In particular it is maintained that the medium used, gelatine with an infusion of some leguminous plant, causes the organism to lose, to a very large extent, its power of fixing nitrogen, because it contains so much combined nitrogen. G. T. Moore, for instance, says: "As a result of numerous trials, however, it has been found that although the bacteria increase most rapidly upon a medium rich in nitrogen, the resulting growth is usually of very much reduced virulence; and when put into the soil these organisms have lost the ability to break up into the minute forms necessary to penetrate the root-hairs. They likewise lose the power of fixing atmospheric nitrogen, which is a property of the nodule-forming bacteria under certain conditions." Latterly the subcultures have been made on media practically free from nitrogen, on agar agar, for example, or on purely inorganic media, supplied, of course, with the carbohydrate, by the combustion of which is to be derived the energy necessary to bring the nitrogen into combination.

In example of the two preparations now being distributed on a commercial scale, the one sent out by Professor Hiltner, of the Bavarian Agricultur-botanische Anstalt, consists of tubes of agar which have to be rubbed up in a nutrient solution containing glucose, a little peptone, and various salts, and this after growth has begun is distributed over the soil or the seeds just before sowing. Moore, of the U. S. Department of Agriculture, finding that the bacterium will resist drying, dips strands of cotton-wool into an active culture medium and then dries them. The cotton-wool is then introduced into a solution containing maltose, potassium phosphate and magnesium sulphate; in a day or two growth becomes active, and the solution is distributed over soil or seed.

It is too early yet to determine what measure of success has been attained by these inoculations with pure cultures; but in considering the results a sharp distinction must be drawn between their use on old cultivated and, such as we are dealing with in the United Kingdom, and under the conditions which prevail in new countries where the land is often being brought under leguminous crop for the first time. Few of our English fields have not carried a long succession of crops of clover, beans, vetches and kindred plants; the *Bacterium radicicola* is abundant in the soil; and, however new the leguminous plant that is introduced, infection takes place unfailingly, and nodules appear. It is true that the organism causing nodulation may not belong to the particular racial adaptation most suited to the host plant, and that in consequence an inoculation from a suitable pure culture might prove more effective. Again, it is possible that even a plant like clover, which would be infected at once through the previous growth of the crop, might be made a greater collector of nitrogen through the introduction of a race of bacteria which had acquired an increased virulence; but in either of these cases the most that could be expected from the inoculation would be a gain of 10 per cent. or so in the crop. This great, though limited, measure of success depends upon two things—on obtaining races of *B. radicicola* possessing greater virulence and greater nitrogen-fixing power than the normal race present in the soil, and again on the possibility of establishing this race upon the leguminous crop under ordinary

field conditions, when the introduced organisms are subject to the competition both of kindred bacteria and of the enormous bacterial flora of any soil. Up to the present all evidence of greater nodule-forming power and increased virulence of the artificial cultures has been derived from experiments made under laboratory conditions without the concurrence of the mass of soil organisms.

In the other case, however, where new land is being brought under cultivation and leguminous crops are being grown for the first time, there can be no doubt of the great value of inoculation with these pure cultures of the nitrogen-fixing organism. An example is afforded in Egypt, where land that is 'salted,' alkali or 'brak' soil, is being reclaimed by washing out the salt; inoculation may be necessary before a leguminous crop can be started on such new land, though in many cases the Nile water used for irrigation is quite capable of effecting inoculation. The body of evidence brought together by the United States Department of Agriculture is very convincing, and shows in repeated examples that the use of Moore's cultures has enabled farmers to obtain a growth of lucerne and kindred plants, which before had been impossible. In view of the economic importance the lucerne or alfalfa crop is assuming in all semiarid climates, the financial benefit to the farming community is likely to be great and immediate. And since in the development of South African farming the lucerne crop is likely to become very prominent, both as the most trustworthy of all the fodder crops and as the one which brings about the maximum enrichment of the soil by its growth, the behavior of the lucerne plant as regards bacterial infection in South African soils is worthy of most careful investigation. It is necessary to know to what extent nodules are formed when lucerne is planted on new soils in South Africa, as, for example, on freshly broken-up veldt; the condition of the organisms within the nodule should be investigated, so as to ascertain if improvement be possible by inoculation from pure cultures, either imported or prepared *de novo* from lucerne within the country. These and kindred questions connected with the symbiosis of the nitrogen-fixing organism and the leguminous plants must to a large extent be worked out afresh in each country, and South Africa, with its special conditions of soil and climate, can not take on trust the results arrived at in Europe or America.

I have spoken of the enrichment of the soil due to growing lucerne, caused by the decay of the great root residues containing nitrogen derived from the atmosphere; an enrichment which is quite independent of the amount of similarly combined nitrogen taken away in the successive crops of leafy growth. Some of the Rothamsted experiments show very clearly how great the gain may be. In the first place I will call your attention to the effect of a crop of red clover grown in rotation upon the crops which succeeded it, since in the Agdell rotation-field we get a comparison between plots growing red clover once every four years and other plots on which a bare fallow is substituted for the clover.

The table shows that in one particular case, when an extra large crop of clover was grown, notwithstanding the fact that the clover plots yielded between three and four tons per acre of clover hay, yet the wheat crop which followed this growth of clover was 15 per cent. better than the wheat crop following the bare fallow. The swede turnip crop, which followed the wheat, although similarly and heavily manured on both plots, continued to be better where the clover had been grown two years previously; and even the barley,

TABLE I.

Manuring for Swede Crop Only.	Clover, 1894.	Wheat, 1895.			Roots, 1896.			Barley, 1897.		
		After Fallow.	After Clover.	Increase Due to Clover.	After Fallow.	After Clover.	Increase Due to Clover.	After Fallow.	After Clover.	Increase Due to Clover.
	Cwt.	lb.	lb.	Per Cent	Cwt.	Cwt.	Per Cent.	lb.	lb.	Per Cent.
Mineral Manure...	59.7	4,220	5,180	+22.7	179.1	244.5	+36.5	2,103	3,991	+89.8
Complete Manure..	76.7	4,547	5,209	+14.6	379.8	388.8	+ 2.4	3,595	4,913	+36.7

which came next, three years after the clover, showed a decided superiority on the clover land. Thus a clover crop, itself wholly removed from the land, exercised a marked influence for good on at least the three succeeding crops grown under the ordinary conditions of farming. Next we can make a comparison between red clover and lucerne. On some of the Rothamsted plots various leguminous plants have been grown for many years, with indifferent success indeed, because of the well-known reluctance of the land to support such crops except at intervals of four or more years. Eventually the plots on which these indifferent crops had been secured were ploughed up and sown with wheat without any manure. In five years the wheat was thus grown on the residues left in the soil by the previous leguminous crops, and from the table will be seen the comparative value of these residues in the case of lucerne and red clover.

TABLE II.

Harvest.	Grain.		Total Produce.	
	After Lucerne.	After Red Clover.	After Lucerne.	After Red Clover.
	Bushels.	Bushels.	Pounds.	Pounds.
1899	39.3	43.0	8,108	8,505
1900	28.9	19.1	4,554	2,992
1901	27.0	21.4	4,054	3,185
1902	20.1	17.7	3,553	3,023
1903	19.9	16.7	3,035	2,528
Total.	135.2	117.9	23,304	20,223

As we have previously seen how great the benefit of a single year's growth of red clover may be on the succeeding crops, an idea can be formed from the comparison in the latter table of how much more lucerne may contribute towards building up a fertile soil; a point which was very markedly brought out in the experiments of the late Mr. James Mason.

The question of the fixation of atmospheric nitrogen by bacterial agencies does not, however, end with the organisms living symbiotically on the leguminous plants, for several other organisms have latterly been discovered which possess the power of fixing nitrogen independently, provided they are supplied with the necessary nutriment. Of late attention has been chiefly directed to a conspicuous organism known as *Azotobacter chroococcum,* which may be readily identified in most cultivated soils. The impure cultures (which may be quickly obtained by introducing a trace of soil into a medium containing no nitrogen, but a little phosphate and other nutrient salts, together with one or two per cent. of mannite or other carbohydrate) fix nitrogen with considerable activity; in one case, for example, when working with a Rothamsted soil, as much as 19 mg. of nitrogen were fixed for each gram of mannite employed and partially oxidized. But Beyerinck, the discoverer of the organism, now attributes the nitrogen fixation to certain other organisms which live practically in symbiosis with the *Azotobacter,* and which are present in the impure cultures just referred to. The exact source of the nitrogen fixation may be left a little doubtful; still the main fact remains that from the bacteria present in many soils one or a group may be found capable of effecting

rapid and considerable nitrogen fixation if the necessary conditions, chiefly those of carbohydrate supply, are satisfied.

But how is the carbohydrate supply to be obtained? Under the normal conditions of arable land farming there are few possibilities in this direction, the occasional ploughing under of a green crop being the only considerable addition of organic matter other than manure, which is possible in practise. As a matter of experience the plots at Rothamsted, which have been growing crops without manure continuously for the last fifty years, indicate but little gain of nitrogen from the atmosphere. After a rapid fall in production for the first few years, the yield has become so nearly stationary that any further decline is not as yet discernible amid the fluctuations due to season.

TABLE III.

Average Amounts of Dry Matter and Nitrogen in Total Produce of Various Crops, grown without Manure at Rothamsted.

	Dry Matter.						Nitrogen.
	Averages Over.					Whole Period.	Whole Period.
	10 Years, 1852-1861.	10 Years, 1862-1871.	10 Years, 1872-1881.	10 Years, 1882-1891.	10 Years, 1892-1901.		
	Pounds.	Pounds.	Pounds.	Pounds.	Pounds.	Pounds.	Pounds.
Broadbalk Wheat.	2,199	1,791	1,346	1,480	1,514	1,666	17.0
Hoos Barley........	2,352	1,797	1,303	1,229	1,120	1,560	15.3
Agdell Rotation[2]..	2,321	1,817	1,403	1,644	1,295	1,696	17.6
Park Hay[3]........		2,082	2,144	2,196	1,421	1,961	33.8

Table III. shows the average yield during the last five decades of dry matter and of nitrogen from four of the unmanured plots at Rothamsted; it will be seen that the difference in the production during the last as compared with the second period of ten years is no more than would be covered by seasonal variations. In other words, the yield, which, as we learn in other ways, is mainly determined by the amount of available nitrogen, has reached a state of equilibrium when the resources of the soil, the material brought down by the rain, and the nitrogen-fixing agencies taken together are just equal to providing the crop with about 17 lbs. of nitrogen per acre per annum in addition to the unknown amounts removed by drainage and in the weeds. The small amount of fixation this indicates and the corresponding low level of production must be set down to the lack of combustible carbohydrate, due to the very complete removal of the various crops from the soil, since the root and stubble left behind after the growth of a cereal crop amount to but a small fraction of the total produce.

In the case of grass-land the conditions are entirely different, especially when we are dealing with wild prairie or forest, where the annual growth of carbohydrate falls back to the soil and is available for such organisms as the *Azotobacter*. At Rothamsted two plots of land which were under arable cultivation twenty-five years ago have been allowed to run wild and acquire a natural vegetation of grasses and weeds, subject to no disturbance beyond the occasional eradication of scrub and bushes. Samples of the soil taken when the land was still under the plough have been preserved, and the comparison of these with new samples drawn during the last year shows enormous accumulations of nitrogen, even when every allowance has been made for certain inevitable errors in

[2] Carted fallow portion.

[3] First and second crops.

sampling the soil (see Table IV.). Of these two fields the Geescroft plots are the more interesting, for though showing the gain of nitrogen is less (45 lbs. per acre per annum against 98 lbs. on Broadbalk), yet continued observation of the herbage that has sprung upon this field has shown the absence of any leguminous plants. According to a botanical analysis made in 1903 the leguminous plants only constituted 0.4 per cent. of the vegetation (as weighed in the dry state) on the Geescroft 'wilderness,' whereas the corresponding plot on Broadbalk contained 25 per cent. Now, with no leguminous plants to act as collectors of nitrogen the considerable gains of combined nitrogen on this Geescroft land must be set down to the work of *Azotobacter* or kindred organisms which get their necessary supply of carbohydrate from the annual fall of the grassy vegetation.

TABLE IV.

Accumulation of Carbon and Nitrogen in Soil of Land allowed to run wild for more than Twenty Years.

		Per Cent. in Dry Soil.			
		Carbon.		Nitrogen	
		1881-3[4]	1904	1881-3[4]	1904
Broadbalk	1st 9 inches.	1.143	1.233	0 1082	0.1450
	2d "	0.624	0.703	0.0701	0.0955
	3d "	0.461	0.551	0.0581	0.0839
Geescroft	1st 9 inches.	1.111	1.494	0.1081	0.1310
	2d "	0.600	0.627	0.0739	0.0829
	3d "	0.447	0.435	0.0597	0.0652

	Broadbalk.		Geescroft.	
	1881	1904	1883	1904
Nitrogen—lbs. per acre..	5,910	8,110	6,043	6,978
Nitrogen—Increase per acre, per annum, lbs..	—	97.8	—	44.5
Ratio of Carbon to Nitrogen....................	9.4	7.7	8.9	9.2
Ratio of Carbon to Nitrogen in Increase......	—	2.9	—	10.7

The fixation of nitrogen must be an oxidizing process, for no other natural reaction is likely to provide the energy necessary to bring the nitrogen into combination. This being so, some light is thrown on the process in nature by an examination of the ratio of carbon to nitrogen in the accumulations referred to above. At starting, the ratio of carbon to nitrogen in the organic matter of the two soils was much the same—a little less than 10 to 1—but the increase of carbon and nitrogen in the Broadbalk field, *i. e.,* the organic matter which has accumulated in the interim, shows a ratio of only 3 to 1, while the corresponding accumulations in Geescroft field show a ratio not far removed from the original of about 11 to 1. In other words, where there has been the greater accumulation of nitrogen on the Broadbalk field, there has been the greater combustion of carbohydrate, so that the accumulation of carbon is actually as well as relatively smaller. Bacteriological tests seem to show a much greater development of *Azotobacter* with increased powers of fixation in the soil from the Broadbalk than from the Geescroft wilderness; a fact to be correlated with the presence of a fair proportion of carbonate of lime in Broadbalk, but not in Geescroft field.

Another example may be drawn from the experiments carried on by the late Mr. James Mason at Eynsham Hall, Oxon. He had large cemented tanks filled with burnt clay mixed with appropriate quantities of calcium carbonate and phosphate and other nutrient salts, but containing no nitrogen. One of these tanks, after inoculation with a trace of ordinary soil, was sown with a mixture of grass-seeds and has carried a weak but purely grassy vegetation ever since. According to a recent analysis the soil of this tank has in fifteen years accumulated 0.029 per cent. of nitrogen in the surface soil and 0.117 per cent. in the second layer—equivalent to about 870 and 350 lbs. per acre per annum,

[4] Broadbalk, 1881; Geescroft, 1883.

the ratio of carbon to nitrogen in the accumulation being about 18 to 1 and 12 to 1, respectively.

Henry has also shown that the shed leaves of many forest trees during their decay may bring about the fixation of nitrogen; and this fact, which again depends on the oxidation of the carbohydrates of the leaf to supply the necessary energy, has been confirmed in the Rothamsted Laboratory, as well as the presence of *Azotobacter* on the decaying leaf.

It is obvious that one of the most interesting fields for the study of these organisms must lie in the virgin lands of a country like South Africa. We all know that virgin soil may, on the one hand, represent land of almost perpetual fertility; on the other, it may constitute wastes of any degree of sterility. What are the conditions under which ensues that accumulation of humus whose nitrogen will become available under cultivation, the 'black soils' famous in every continent? The ecological botanists are working out some of the great climatic conditions, the amount and distribution of rainfall and temperature which are associated with 'steppe' areas of great accumulated fertility, but the bacterial flora which is fundamentally bound up with the problem remains as yet unexplored.

It is possible also that on some of the newer lands this and kindred bacteria are absent because the conditions are not entirely suitable to their development. A. Koch has shown that the presence of calcium carbonate is necessary to the action of *Azotobacter*, and determinations of the power of soils from the various Rothamsted fields to induce fixation confirm his results, the development of the organism in question being feeble when the soil was derived from some of the fields that had escaped the 'chalking' process to which the calcium carbonate of the Rothamsted soils is due.

The value of calcium carbonate in this connection only adds to the many actions which are brought about by the presence of lime in the soil—lime, that is, in the form of calcium carbonate, which will behave as a base towards the acids produced by bacterial activity. The experimental fields at Rothamsted afford a singular opportunity of studying the action of lime, since the soil, a stiff, flinty loam, almost a clay, is naturally devoid of calcium carbonate, though most of the cultivated fields contain now from 2 to 5 per cent. in the surface soil, due to the repeated applications of chalk, which used to be so integral a part of farming practise up to the middle of the nineteenth century. Where this chalking process has been omitted, as is the case in one or two fields, the whole agricultural character of the field is changed: the soil works so heavily that it is difficult to keep the land under the plough; and as grass land it carries a very different and altogether inferior class of vegetation. On the experimental fields it has been possible to measure the rate at which natural agencies, chiefly the carbonic acid and water in the soil, are removing the calcium carbonate that has been introduced into the surface soil, and it is found to be disappearing from the unmanured plots under arable cultivation at an approximate rate of 1,000 lbs. per acre per annum; a rate which is increased by the use of manures like sulphate of ammonia, but diminished by the use of nitrate of soda and of dung. Failing the renewal of the custom of chalking or liming—and its disuse is now very general—the continuous removal of calcium carbonate thus indicated must eventually result in the deterioration of the land to the level of that which has never been chalked at all, and even a state of sterility will ensue if much

use is made of acid artificial manures. That many soils containing naturally only a trace of calcium carbonate remain fairly fertile under ordinary farming conditions is due, on the one hand, to an action of the plant itself, which restores to the soil a large proportion of the bases of the neutral salts upon which it feeds, and partly to the action of certain bacteria in the soil, which ferment organic salts like calcium oxalate existing in plant residues down to the state of carbonate. Were it not for these two agencies restoring bases the soil must naturally lose its neutral reaction, since the process of nitrification is continuously withdrawing some base to combine with the nitric and nitrous acids it sets free.

This varying distribution of calcium carbonate in soils suggests another section of my subject, in which great activity has prevailed of late—the undertaking of a systematic series of soil analyses in any district, with a view to making soil maps that shall be of service to the agriculturist. The Prussian government has long been executing such a soil survey, and during the last few years a similar project has been pushed forward with great energy in the United States; in France and in Belgium several surveys are in progress, but in the United Kingdom the matter has so far only excited one or two local attempts. While the basis of such work must always be the geological survey of the district, a geological survey in which, however, the thin 'drift' formations are of greater importance than the solid geology, there are certain other items of information required by the farmer which would have to be supplied by the agricultural specialist. In the first place, the farmer wants to be told the thickness of the superficial deposits; he requires frequent 'ground profiles,' so that he can construct an imaginary section through the upper 10 feet or so of his ground. To take a concrete example: the chalk in the south of England is very often overlaid by deposits of loam, approaching the nature of brick earth, and the agricultural character of the land, its suitability for some of the special crops, like hops and fruit, which characterize that district, will be wholly different according as the deposit is 3 feet or 10 feet deep. The proximity and, if near the surface, the direction of flow of the ground water are also matters on which there could be given to the farmer information of great importance when questions of drainage or water-supply have to be considered. It is necessary also to refine upon the rough classification of the soil and subsoil which alone is possible to the field surveyor, one of whose functions will be to procure typical samples of which the texture and physical structure can afterwards be worked out in the laboratory. Geological formations are constantly showing lithological changes as one passes along their outcrop either in a vertical sense or in their lateral extension; and these changes are often reflected by corresponding changes in the character of the soil which are of commercial importance.

But while the mechanical analysis of the soil has been of late the basis upon which all soil surveys are constructed, it is of equal importance, at any rate in the older countries under intensive cultivation, to undertake certain chemical determinations, which come to possess a new value when taken in connection with a soil survey. It has been generally demonstrated that an analysis, physical and chemical alike, of the soil of a particular field, taken by itself, possesses but little value. The physical analysis will indicate roughly the character of the soil, but very little better than could have been learned by walking over the soil and digging in it for five minutes; the chemical analysis will disclose any glaring deficiencies; but, as a rule, the analytical

figures will be of a very indecisive character, and will lead to little information of practical value. This is because the productivity of a given piece of land depends upon a large number of agencies, any one of which may be the limiting factor in the crop yield. We may enumerate, for example, temperature and water-supply, both determined by the climate, by the natural physical structure of the soil and by the modifications in its texture induced by cultivation; there are further the aeration and the actual texture of the soil, the initial supply of plant-food of various kinds and, again, the rate at which this last item is rendered available to the plant by bacterial action or by purely physical agencies. All these factors interact upon one another. To all of them and not merely to the nutrient constituents does Liebig's law of the minimum apply; so that any one may become the limiting factor and alone determine the yield. It is of no use, for example, to increase the phosphoric-acid content of a soil, however deficient it may be, if the maximum crop is being grown that is consistent with the water-supply, or if the growth of the plant is being limited by insufficient root range caused by bad texture and the lack of aeration in the soil. However much we may refine our methods of analysis, we may take it as certain that we shall never be able to deduce *à priori* the productivity of the soil from a consideration of the data supplied by the analysis. The function, then, of soil analysis is not to make absolute deductions from the results, but by a comparison of the unknown soil under examination with other soils already known to interpret the divergences and similarities in the light of previous experience. That a given soil contains one tenth per cent. of phosphoric acid or one fiftieth per cent. of the same constituent soluble in a dilute citric-acid solution is in itself meaningless information; but it becomes of great value when we know that the normal soils of that particular type contain less than this proportion of phosphoric acid as a rule, and yet show no particular response to phosphatic manuring.

What, then, the soil analyst can do is to characterize the type, ascertain its normal structure and composition, and correlate its behavior under cultivation, its suitability for particular crops and its response to manuring in various directions. Thus an unknown soil may by analysis be allotted to its known type, deviations from the type can be recognized and conclusions may be drawn as to the connection of these defects.

Valuable as recent development of soil analysis may have been (and I allude in particular to the improvements in the methods of mechanical analysis which have been worked out in the United States Department of Agriculture, to the many investigations that have been made on the measurement of 'available' plant-food by attack with weak acid solvents, to the determinations of the bacterial activity of the soil), the results they yield can only be truly interpreted when they can be compared with a mass of data accumulated by the use of the same methods on known soils.

One of the services, then, which the farmers in every country may very properly expect from the scientific man is such a survey of the principal soil types, affording the necessary datum lines by which the comparative richness and poverty of any particular soil may be gauged. In an old settled country like the United Kingdom such a survey would guide the farmer in his selection of manures; in a new country the advantages would be even more apparent, as the areas appropriate to particular crops would be indicated, and settlers would be saved from many expensive attempts to introduce things for which their land was unsuited.

It would also be possible to indicate the

measures which should be taken to ameliorate the nature of the poorer soils, for, remote as may now seem the prospects of spending time and labor on bad land in new countries where there is still a choice of good, once the road to improvement is indicated little by little the work will be done. It is hardly realized to what extent the soils in England have been 'made'; the practise of 'chalking,' previously mentioned as having doubled or trebled the value of the Rothamsted land, must have added between 100 tons and 200 tons of chalk per acre to those soils before the end of the eighteenth century, and in other parts of the country marling, claying, incorporation of burnt earth and other lighter material have contributed enormously to render the present degree of fertility possible.

The main facts of the nutrition of the plant have been so long established that it is not always realized how much still remains unknown. It has become a commonplace of the text-books that the plant needs nitrogen, phosphoric acid, potash, often in excess of the quantities present in a normal soil; so that these substances alone are considered of manurial value, other necessary materials like lime, magnesia, iron, sulphuric acid and chlorine being practically never lacking under natural conditions. But the function of these substances in the development of particular plants, the manner in which the character of the crop is affected by an excess or a deficit, is still imperfectly apprehended. We realize the dependence of vegetative development upon the supply of nitrogen, and how an excess defers maturity; we are also beginning to gather facts as to the manner in which an overplus of nitrogen causes alterations in the structure of the tissues and variations in composition of the cell contents that result in increased susceptibility to fungoid attack. Again, it is clear that potash takes a fundamental part in the process of assimilation, the production of carbohydrate in all forms being dependent on the supply of potash; but of the manner or the location of the action we have no knowledge. Our ignorance of the function of phosphoric acid is even greater; broadly speaking, it hastens maturity, and is bound up with such final processes in the plant's development as the elaboration of seed. With this we naturally correlate on *à priori* grounds the presence of phosphorus in the nucleoproteids; but there is no particular evidence that excess of phosphoric acid leads to increased assimilation of nitrogen.

Some of the barley plots at Rothamsted show this very clearly; where there has been no phosphatic, but a nitrogenous, manuring for the last fifty years, the amount of nitrogen assimilated by the crop is diminished, but the gross production of dry matter is still further diminished. By the addition of phosphoric acid the gross production is increased to a greater degree than the amount of proteid formed is increased, so that the crop shows now a smaller percentage of nitrogen and a lower ratio of nitrogen to phosphoric acid than on the plots which are experiencing phosphoric-acid starvation. In other words, where an excess of nitrogen is available the amount assimilated does not increase *pari passu* with the amount of phosphoric acid which the plant can obtain.

But with these three substances all exact knowledge ceases; magnesia, sulphuric acid and chlorine are invariable and necessary constituents of all plants, yet their function and their practical effects are still unknown. To take a further example, it was early in the history of agricultural science that silica was discovered to be the chief constituent of the ash of cereals and of a few other plants. Liebig's term of 'silica plants' still survives to show the importance once attached to this body, and

the earlier experimenters with manures used soluble silicates with the idea of thereby increasing the stiffness of straw. But further investigations showed that cereals could be brought to maturity without any supply of silica, and that the stiffness of the straw was a physiological matter in no way conditioned by silica. As a consequence this plant constituent has now been disregarded for a long time. But it is idle to suppose that a substance present, for example, to the extent of 60 per cent. or so in the ash of the straw of wheat, has no part to play in the nutrition of the plant. Among the Rothamsted experiments there are fortunately some barley plots which have received soluble silica for many years, and a recent examination of the material grown on these plots begins to cast some light on the function of silica. Its effect upon the plant is in some way parallel to that of phosphoric acid; on the plots which have had no phosphatic manure for more than fifty years an addition of soluble silica increases the crop, increases the proportion of grain and hastens the maturity in exactly the same fashion, though to a less degree, than an addition of phosphoric acid. The results point to the plant rather than the soil as being the seat of the action; a plant that is being starved of phosphoric acid can economize and make more use of its restricted portion if a quantity of soluble silica be available. There is no possibility of replacing phosphoric acid by silica in the general nutrition of the plant, but the abundance of silica at the disposal of the cereals certainly enables them to diminish their call for phosphoric acid from the soil.

Much in the same direction lie the researches which are being pursued with so much vigor by Loew and his pupils in Japan on the stimulus to assimilation and plant development which is brought about by infinitesimal traces of many metallic salts not usually recognized as being present in plants at all. It has been often recognized that substances which are toxic to the cell in ordinary dilutions may, when the dilution is pushed to an extreme, reach a point at which their action is reversed and begins to stimulate. Probably some of the materials used as fungicides and inhibitors of disease act in this fashion by strengthening the whole constitution of the plant rather than by directly destroying or checking the growth of the fungus mycelium. The subject is certainly one which promises to yield results of value in practise, and calls for more extended and exact observation.

The importance of research on the particular function of the various constituents of the crop lies in the fact that it is only by the possession of such knowledge we may possibly influence in desired directions the quality of our crops. With the effect of manuring upon the yield of most of our crops we are now familiar, but the question of 'quality,' almost as important as that of yield, forms a more difficult problem. One particular example may be cited, that of wheat, because of late years it has been a subject of investigation in most wheat-producing countries. That quality of wheat which is of special commercial importance is its so-called 'strength,' the capacity of yielding flour of such a consistency in the state of dough as will retain the gases produced in fermentation with the formation of a tall, well-piled loaf. This property of 'strength' is usually found in a hard horny and translucent grain, the soft, mealy-looking wheats being as a rule 'weak.' Again, the strong wheats usually originate from districts like the Hungarian plain, the Northwest of America, and south Russia, countries characterized by a typical continental climate, cold and dry in the winter, with rains in the late spring and early summer, and a gradually increasing dry-

ness and temperature up to the time of harvest. The wheats grown under the opposite conditions of a winter rainfall and a dry summer, as on the Pacific slope of North America, or an evenly distributed rainfall as in England or France, are on the whole weak. The differences in this quality are considerable when measured commercially; for example, in most seasons the best Manitoban wheat will be worth 20 to 25 per cent. more than a corresponding grade of English wheat on the London market. The source of strength lies among the nitrogenous constituents of the wheat flour; it can be measured roughly either by determining the proportion of nitrogen in the flour, or by the old process of washing away the starch and leaving the gluten. Neither process agrees exactly with baking tests, nor do any of the more recent attemps to differentiate the wheat proteids by their solubility in various media, as, for example, the determination of the so-called *gliadin glutenin ratio.* In fact, in the present state of our knowledge of the possibilities of identifying and separating the proteids in a pure state, there is little likelihood of being able to make out the subtle differences of chemical composition which result in the varying quality of the wheat proteid mass. For example, the relative strength of different varieties of wheat grown under similar conditions will follow the order in which the wheats are placed by their content in nitrogen; yet if, as at Rothamsted, an increased nitrogen content in the wheat is brought about by excessive nitrogenous manuring, the product is actually considerably weaker than wheat on the other plots grown under more normal conditions. The manuring, while increasing the nitrogenous matter of the wheat, has probably introduced a new factor in the shape of a more prolonged development resulting in the lack of those final changes in the nature of the wheat proteids which make for strength. This seems to be indicated by the fact that on storage this particular abnormal wheat gradually increases in strength up to the normal, though never to the degree that would be indicated by its nitrogen content. But though the chemical methods of estimating the strength of wheat have as yet proved inconclusive, some idea of the factors determining this quality has been reached from practical baking tests combined with measurements of the gluten and nitrogen content of the flour. In the first place manuring proves a very small factor; the composition of the grain of wheat is extraordinarily stable and the plant reacts to diversities in nutrition by producing more or less grain rather than by altering its composition. Even under the exceptionally pronounced variations in the manurial conditions of the Rothamsted plots, the composition of the grain fluctuates more with changing seasons than with changed manuring. Within the limits of healthy growth and ripening the date of sowing the wheat has no effect upon the quality of the grain; the same wheat sown at monthly intervals from October to March gave practically identical quality in the grain, and a number of comparisons between autumn and spring sowing led to no definite conclusion. Soil has also a comparatively small effect, though, of course, different soils, by inducing differences in the supply of water to the plants and in the temperature, practically result in differences of climate. The effect of climate is large, whether tested by growing the same variety in different countries or by inducing artificial variations in the climate of wheats grown under experimental conditions. But while the climatic factor proves to be large it is less than was anticipated; an English soft wheat, for example, grown on the Hungarian plain for two seasons, has not altered greatly in character nor taken on the characteristic ap-

pearances of the wheat of the district. A specially strong wheat from the Canadian Northwest, after some considerable fall of strength in the first English crop, has fallen no further after three successive crops, and still retains all the characters of an exceptionally strong wheat, although the yield remains poor from an English standpoint. Other varieties have rapidly and entirely lost their strength when changed to English conditions from America, or Hungary, or Russia; many, however, while showing the effect of climate, yet stand apart from the typical English wheats and show no tendency to 'acclimatize' in the sense of acquiring the character of the local varieties. In the whole work the thing which stands up most prominently is the fundamental importance of the 'variety'; each race, each botanical unit as it were, possesses an individuality and yields grain of a characteristic composition; and though climate, soil, season, manuring, are factors producing variation in the composition, they are all small compared with the intrinsic nature of the variety itself. Similar conclusions follow from the work of Wood and his colleagues upon the composition of mangels, and of Collins on the composition of swedes. The proportion of dry matter and sugar in the root, while varying markedly in the individual roots, possesses a typical value for each race; and though season, locality and to some extent manuring affect the composition, the changes thus induced are not great.

Starting, then, from this point, that variety or race is the chief factor in the composition of a given plant, and that, once the variety is fixed, the other factors, which are more or less under control, such as manuring, soil and climate, have but minor effects upon the quality, the road to the improvement of the quality of our farm crops lies in the creation of new varieties by breeding. An improved variety is all clear gain to the farmer; climate, season and to a large extent soil are outside his control; while better manuring and cultivation, however much their cost may be lessened by increased skill, yet involve expenditure and become unremunerative above a certain point. But an improved variety, without costing any more to grow, may increase the returns by 10 or 20 per cent., in some cases may nearly double them.

As regards the value of selection, Wood shows that the composition of the mangel, which has been selected solely for such external qualities as shape and habit, has remained stationary during the fifty years or so for which we possess any information; while between 1860 and 1890 the sugar beet has had its sugar content raised from an average of 10.9 to 15 per cent. by the steady selection of seed-mothers for their richness. The prospects of breeding new varieties of wheat, and particuarly of securing improvements in such qualities as 'strength,' have been enormously improved within the last year or two through the investigations which have followed on the rediscovery of Mendel's law of inheritance. Wheat as a normally self-fertilized plant is particularly suited to the investigation of Mendel's law, and the work of Biffen shows that, with a few possible exceptions, the characters of the parent varieties are inherited strictly in accordance with the expectations derived from a consideration of that law. The great practical importance of this generalization lies in the fact that it thus becomes possible to pick out with certainty fixed types in the third generation of the hybrids, whereas without the guidance of Mendel's law and working by the old plan of selection, followed by continuous 'rogueing,' it was impossible ever to secure a pure strain unless by chance an individual possessing

pure recessive or pure dominant characters had been hit upon from the first.

Biffen's work further indicates that the power of producing a glutinous grain, such as will lead to 'strength' in the flour, is a Mendelian character, following the same laws of inheritance as the bearded or beardless habit or the color of the grain or chaff. Extreme strength shown in any particular wheat can then be picked out and combined with any other essential qualities, such as the yield and the character of the straw, which distinguish our present varieties of wheat. Of course the inheritance of a quality like strength, which is only relative between different varieties, can not be traced with the sharpness with which such characters as the long-awned bearded type can be followed; still the variation that is, as it were, superimposed upon the 'strength' or 'weakness' representing the inherited Mendelian character is not sufficient to obliterate the evidence of inheritance according to the law. And, of course this variation of individual seedlings in the 'strong' section above and below the degree of strength possessed by the parent, *i. e.*, the inherited character, gives the plant-breeder his opportunity of improving such a quality at the same time as he is combining with it the other characteristics that are desired in the new varieties. Biffen's work among the wheat hybrids touches also upon another point of special importance to South African farming, where the incidence of 'rust' forms the greatest obstacle of extensive and successful wheat-growing. The climatological conditions which make for a rust attack have not been worked out, as far as can be judged from the behavior of English wheats in various seasons, together with the prevailing climates in countries where rust is specially prevalent; a flush of growth in the spring followed by high temperatures will favor the disease, but South Africa, with its great variations in the amount and incidence of the rainfall and with its very different temperatures, affords a very good opportunity for obtaining information on this point. Returning, however, to the question of variety, it is generally recognized that relative immunity or susceptibility to an attack of yellow rust is characteristic of particular varieties, and Biffen finds that such 'immunity' is a true Mendelian character, recessive and therefore only appearing in the second generation of hybrids between a rusting and rust-proof parent. It is not correlated with shape or character of the leaf, but is transmitted from one generation to another quite independently, and can, therefore, be picked out of a desirable parent and combined with other qualities of value in different parents. Here, again, we are dealing with a character that is only relative, for no wheat can be called either absolutely rust-proof or entirely susceptible; the offspring that have inherited immunity will still vary a trifle among themselves in the degree of their resistance to attack, and in this possibility of variation lies the chance of the plant-breeder to improve upon the rust-resisting powers of the varieties we now possess.

The whole work of the plant-breeder is of singular importance in a country like South Africa whose agricultural history is so recent. Our European crops represent the culminating points of a tradition, and are the fruit of the observation and judgment of many generations of practical men working, as a rule, with chance material. The products are eminently suited to European conditions, but, as has been seen so often, they fail comparatively when brought into other climates and soils. It follows, then, that in a new country the work of the acclimatizer is one of the necessary foundations for agriculture, and this involves a careful study of climatology

and of the influence that the distribution of rainfall and temperature in various parts of the country has on the character of the crop.

Then the cross-breeder's work begins: acclimatization alone is hardly likely to yield the ideal plant, but by it are found plants possessing the features, one here and one there, that are desiderated; and starting with this ground material the hybridizer can eventually turn out an individual possessing to a large measure all the qualities that are sought for.

There is little hope that science can do anything wholly new for agriculture; acclimatization, breeding and selection have been the mainstay of farming progress since the beginning of time, just as the action of the nitrifying bacteria and of nitrogen fixation by the leguminous plants was instinctively apprehended by the earliest farmers of whom we have any record.

But with increasing knowledge comes more power, and particularly the possibility of accelerating the rate of progress; agricultural improvements in the past have resulted from the gradual and unorganized accretions of the observation and experience of many men, often of many generations, now that we are provided by science with guiding hypotheses and by the organization of experiment with the means of replacing casual opinions by exact knowledge. Even the properties of the soil and the character of our farm crops and animals—stubborn facts as they are and deeply grounded in the nature of things—ought to become increasingly plastic in our hands.

A. D. HALL.

SCIENTIFIC BOOKS.

Physiological Economy in Nutrition. By RUSSELL H. CHITTENDEN, Ph.D., LL.D., Sc.D. New York, F. A. Stokes Co. 1904.

This notable volume, the production of Professor Chittenden and his coworkers, of whom Professor Lafayette B. Mendel is the most prominent, finally dispels the tradition that a continued liberal allowance of proteid in a normal diet is a prerequisite for the maintenance of bodily vigor.

Professor Chittenden had suffered from persistent rheumatism of the knee joint and determined on a course of dieting which should largely reduce the proteid and calorific intake. The rheumatism disappeared and minor troubles such as 'sick-headaches' and bilious attacks no longer recurred periodically as before.

> There was a greater appreciation of such food as was eaten: a keener appetite, and more acute taste seemed to be developed and a more thorough liking for simple foods.

During the first eight months of the dieting there was a loss of body weight equal to eight kilograms. Thereafter for nine months the body weight remained stationary.

> Two months of the time were spent at an inland fishing resort, and during a part of this time a guide was dispensed with and the boat rowed by the writer frequently six to ten miles in a forenoon, sometimes against head winds (without breakfast) and with much greater freedom from fatigue and muscular soreness than in previous years on a fuller dietary.

During this latter period of nine months the nitrogen of the urine was determined daily. The average was 5.69 grams. During the last two months this was reduced to 5.40 grams. Experiments showed that about one gram of nitrogen was eliminated in the fæces, and that nitrogen equilibrium could be maintained with dietaries of low calorific value (1,613 and 1,549 calories) containing 6.40 and 5.86 grams of nitrogen. These figures correspond to diets containing 40 and 36.6 grams of proteid instead of 118 grams commended by Voit and honored by habit and tradition. The foods with the strongest flavors are meats.

Professor Chittenden believes that the large quantity of proteid in the ordinary diet is due to self-indulgence. He protests against such indulgence and believes that a futile strain is thereby placed upon the liver, kidneys and other organs concerned in the transformation and elimination of the end products of proteid metabolism.